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Development of the energy efficient residential low-rise house concept for the Ural region

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Abstract. In the article the problem of energy-efficient construction in Russia is considered. The energy-saving technologies and renewable energy sources acceptable in construction in the Ural region analysis is carried out. Main reasons of the irrational consumption of thermal energy are highlighted and the strategy of the energy-efficient construction development in the Urals is described. As a result of the research, a conceptual project of an individual residential house was developed.

1. Introduction

The problem of ecological and energy-efficient construction development in the Russian Federation from year to year is becoming increasingly popular and widely discussed. There are different ways to develop energy efficiency depending on the climatic conditions of the country. Primarily it depends on the characteristics of energy consumption. While in the southern countries the main proportion of energy is spent on air conditioning, in Russia up to 40% of countrywide energy resources goes to heat buildings in the winter and large amounts of carbon dioxide are emitted into the atmosphere, which leads to a "greenhouse effect". Therefore, the environmental situation, the economic growth of the country and the living standard of citizens depend on the results of solving this problem. It is obvious that technologies aimed at reducing heat loss and automating the processes of thermal energy consumption will provide the greatest economic effect.

Despite numerous discussions of this problem, there are only a few dozen implemented projects in Russia using energy efficient technologies and materials. In most projects, "energy efficiency" is limited only by improved glazing and an automated lighting system.

2. Problems of energy-efficient construction growth lack in Russia

Why the problem is still not solved? There are five key reasons hindering the development of energy-efficient technologies in the Russian construction industry.

The first one is the lack of a competent regulatory framework. In 1996 the State Duma adopted federal law No. 28 of April 3, 1996 "Energy-saving", in which the issue of energy efficiency was mentioned for the first time. The main objects of regulation were: efficient use of energy resources, starting from their extraction and ending with consumption; control over the efficient use of energy resources through the state; creation and development of alternative options for expensive and rare energy resources; the creation and development of energy-efficient technologies, metering and control of energy resources, the introduction of new modern energy-efficient materials, products, structures; ensuring the uniformity of measurements in the field of energy resources.



Due to the above requirements, their main solution was the widespread use of multilayer wall structures. Thus, in accordance with modern building codes, the required resistance to heat transfer, for example, of walls was increased by 3-3.5 times in comparison with the old standards.

The second reason that hampers the development of energy-efficient construction is that it is expensive at relatively low utility rates for Europe. The cost price per square meter in an energy-efficient eco-house is higher than usual on average by 20%, while the payback comes at least after 20 years.

The third reason is the lack of cheap domestic materials that meet the requirements of energy efficiency and environmental friendliness. Over the past 20 years, investment in the research sector in the field of construction has been minimal. Therefore, most materials are either imported or produced in Russia using foreign technologies.

The fourth is the complexity of the process of introducing energy efficient technologies. The development of energy efficiency requires a serious technical, scientific approach. It is necessary to consider the existing experience and project it on the climatic features of the country. The task is complicated by the lack of qualified personnel: they are mainly represented by employees of foreign companies or Russian specialists trained abroad.

The last problem is social. The majority of Russian citizens are not aware or not enough aware of this problem. The other part is not ready to sacrifice personal amenities and well-established household habits for the sake of improving the energy efficiency of their homes and using environmentally friendly materials. Not every citizen of the Russian Federation is concerned about the problem of ecology in the country and the world, the results of which we can observe every day in almost every city in the country.

Obviously, government support is necessary for the effective implementation of an energy saving strategy. The government has to stimulate domestic producers of building materials so cheap products can appear on the market. It is also extremely important to develop a mechanism for interaction with the scientific sector, since at present relatively few specialists deal with this problem.

3. Development of energy efficient construction in the Urals

The greatest impetus to the development of energy-efficient construction in Russia will come from the development of an energy-saving and energy efficiency strategy for each region based on its climatic features. Let us analyze energy efficient technologies acceptable for the Ural region.

3.1. Architectural and technological strategies for energy saving in the Urals

Currently, according to expert estimates, the specific heat losses in buildings are distributed as follows: up to 40% due to organized and unorganized infiltration of heated air, up to 30% due to insufficient heat transfer resistance of enclosing structures, up to 30% due to wasteful use of hot water and unregulated mode of operation of heating systems [1]. The complex of energy saving measures corresponding to the energy saving strategy in the Ural region can be divided into five main groups:

- town planning solutions;
- architectural and planning solutions;
- constructive systems;
- engineering systems;
- renewable energy sources.

The combination of energy-saving urban planning activities includes: the organization of the planning structure of neighborhoods from semi-enclosed residential groups that open to the south side of the horizon; compactness of the complex development of micro-districts due to an increase of the construction density; application of wind-shelter in the formation of residential groups to reduce infiltration heat losses from wind exposure; the use of blocking buildings, allowing to significantly reduce their heat loss; optimization of the location of the network of service institutions in the form of compact public, commercial, sports and recreational, cultural and entertainment, and other centers of various levels of service; integrated development of underground space [2].

Significant impact on the specific heat loss in residential and public buildings has their space-planning decisions and, in particular, the ratio of the enclosing structures area to the total area of buildings, placing them on the relief and relative to the cardinal points. The recommended complex of architectural and planning solutions includes: the choice of the optimal shape of buildings, characterized by a high compactness factor and ensuring minimal heat loss in the winter period and minimal heat gain in the summer period; the choice of the optimal orientation of buildings to the cardinal points, taking into account the prevailing wind direction in the winter period; reduction of the area of external enclosing structures by reducing the perimeter of external walls due to the rejection of the facades roughness and of the “architectural openings”; communication of premises without excessive corridors, halls and dark rooms [3].

The most rational types of energy-efficient exterior walling are multi-layer composite structures of walls and coatings using mineral efficient materials. Warming of external walls - the most expensive and labor-intensive process - reduces the heat loss by about 12–15%. Heat loss through the windows reaches 50% of the total heat loss through the building envelope, so the first step is to improve the heat-shielding qualities of the windows. For example, the use of windows with heat-reflecting glass in residential construction allows reducing heat loss through them up to 40% of energy.

Approximate calculations show that with the cumulative implementation of measures to modernize engineering systems, it is possible to reduce the heat consumption in residential and public buildings for heating and heating of inflowing or infiltrating air by 30–40%. At the same time, one-time capital costs will be significantly (from 2 to 10 times) lower than the costs of increasing the thermal resistance of the walls.

A significant energy saving effect can be realized through the use of renewable energy sources [4]. These types include: the energy of the sun, wind, heat of the seas and oceans, land (geothermal energy), and hydropower.

Thus, the main strategies for the development of energy conservation in the construction and operation of buildings and structures are as follows:

- 1) A systematic approach and an economically sound sequence of implementation of a interrelated and interdependent energy-saving measures of urban planning, architectural planning, constructive, engineering and operational nature set.

- 2) The program-targeted method of developing and implementing a system of energy-saving measures aimed at obtaining the final result – maximum savings of non-renewable fuel resources with minimal expenditure of funds and time to achieve this goal.

- 3) Orientation of scientific, design and practical activities on energy saving to the most energy-intensive area of fixed assets operation, the implementation of energy-saving technologies in which more than 90% of the potential effect on energy-saving provides through the modernization and reconstruction of buildings, structures, utilities, communications and energy facilities.

3.2. Renewable energy sources for the Urals

The economic costs of heating and hot water in the Ural region reach 40% of the total energy consumption. Two options for heating and hot water installations will be considered further: on the basis of a solar collector and on the basis of a heat pump.

For heat engineering calculation and calculation of heat losses, we take as a basis a three-storey individual residential house with an area of 280 m² (figure 1). The composition of the wall consists of: wooden frame, mineral wool insulation Tizol EURO-Vent, facade system with a ventilated gap. Heater Tizol EURO-Vent [5]: 70 mm – in the composition of the outer wall (residential premises), 80 mm – for combined bathroom, 50 mm – garage, 200 mm – in the composition of the coating (residential floor).

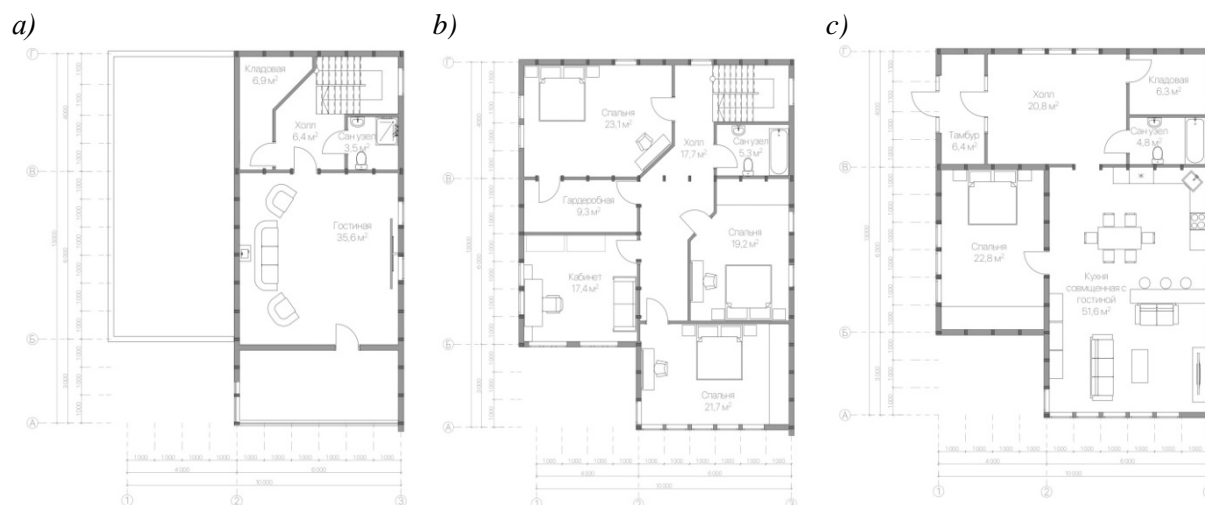


Figure 1. Plans for an individual residential building: *a* – first floor, *b* – second floor, *c* – third floor.

With such building parameters, the heat loss through the fence and for infiltration amounted to 9.7 kW, which must be compensated by heating system. The consumption of hot water per person is an average of 4 m³ per month. For example, in a house adopted for the calculation four people live permanently, then such a family will spend 16 m³ of hot water per month or 192 m³ per year [6].

Next, we will consider two options with using renewable energy sources installations: a solar collector and a heat pump, and also without the use of renewable energy sources - an electric boiler (figure 2).



Figure 2. *a* – Solar vacuum collector SCH-24-15 for year-round use; *b* – Meeting-MDS60D water-to-water heat pump; *c* – Electric boiler class Comfort Plus.

Solar collectors are a source of free and clean energy. They convert direct and diffused sunlight into heat. Taking into account the seasonal changes in solar radiation in the Urals region 14% of the total generated heat will be produced in the winter, 29% in the spring, 36% in the summer and 21% in the autumn. In December and January, heat generation is minimal, and will amount to 3.3% per month of total heat production per year [7]. That is why the solar collectors are rarely used for heating in this climate.

We obtain that the system with the solar collector for heating and hot water will require 6 704 kWh per month in the heated period (from October to April) and 288 kWh per month in the unheated period (from May to September) [8]. The cost of electricity for heating and hot water are shown in Table 2.

The principle of operation of a water-to-water heat pump is the selection of heat energy from a low-grade heat source and its direction to heat the building. The coefficient of efficiency of heat pump is greater than one by 3-4 times.

When using heat pumps for heating and hot water, 1 852 kWh per month during the heated period and 223 kWh per month during the unheated period [9] are required, costs are shown in Table 2.

Let us compare the costs with the option of heating and hot water without the use of renewable energy (Table 1).

Table 1. Energy consumption for heating water per month, kWh.

Period of time	Type of heater		
	Solar collector	Heat pump	Electric boiler
October-April	6704	1852	7910
May-September	288	223	953
TOTAL, kWh (per year)	48 368	14 079	60 135

Required installation costs and costs during operation, (Table 2) payback period [10], (Figure 3).

Table 2. Costs and service life of various heating systems and hot water supply.

Costs	Solar collector	Heat pump	Electric boiler
Installation cost, rub.	332 800,00	179 200,00	39 800,00
Service, rub.	30 000,00	50 000,00	10 000,00
Electricity costs per year, rub.	188 151,52	54 767,31	233 925,15
Service life, year	15	15	5

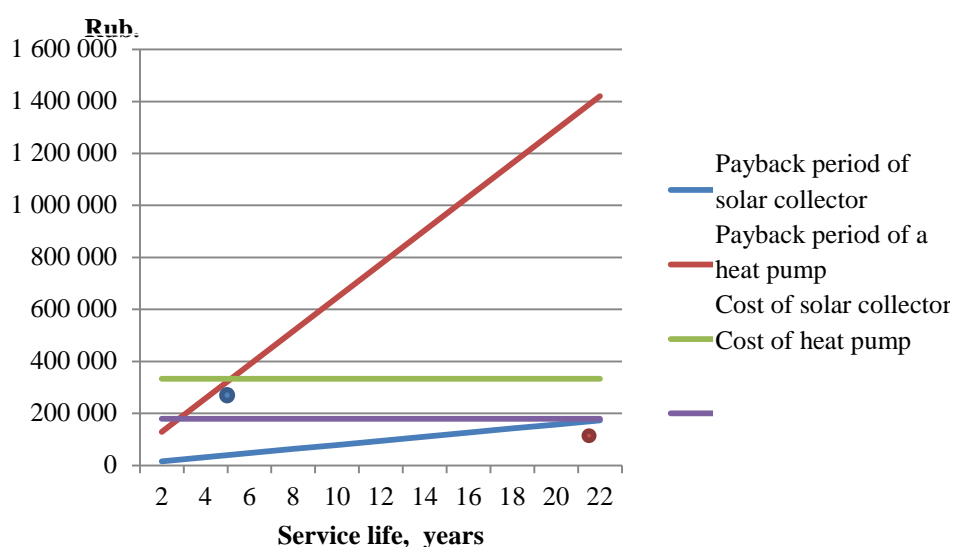


Figure 3. Payback periods.

From this chart it is clear that a system with a solar collector will pay off in 21 years and a system with a heat pump in 1.5 years. So the payback period of the heat pump will exceed 14 times the payback period of the solar collector. Such a large gap appears due to the fact that the solar collector power is not enough for heating in winter in the conditions of the Ural region [11]. Therefore, in these climatic conditions, it is more reasonably to use a heat pump or a combination of a heat pump and a solar collector [12].

4. The concept of an energy efficient low-rise house for the Ural region

The complex of energy-saving measures, consisting of five main groups: urban planning solutions; architectural planning solutions; structural systems; engineering systems; as well, the analysis of renewable energy sources made it possible to form the concept of an energy efficient low-rise house for the Urals region (Figures 4-6).



Figure 4. Conceptual project of energy-efficient residential building.

The concept of an energy efficient house for the Ural region includes:

- an effective thermal envelope of the building, with an optimal heat transfer coefficient of external walls, and a compact layout, which create a closed loop of the building that provides an increase in energy efficiency;
- pitched roof with a warmed attic - the most effective way to cover an individual house in these climatic conditions, allowing to place solar collectors at a certain angle;
- the presence of a warmed portal and a heat-reflecting triple glazed window, which allows to reduce the largest part of heat losses attributable to windows and doors;
- the location and size of the windows according to the cardinal points, which contributes to the most efficient use of solar radiation;
- installation of a vacuum solar collector system and a heat pump that make the heating and hot water supply of a residential building autonomous.

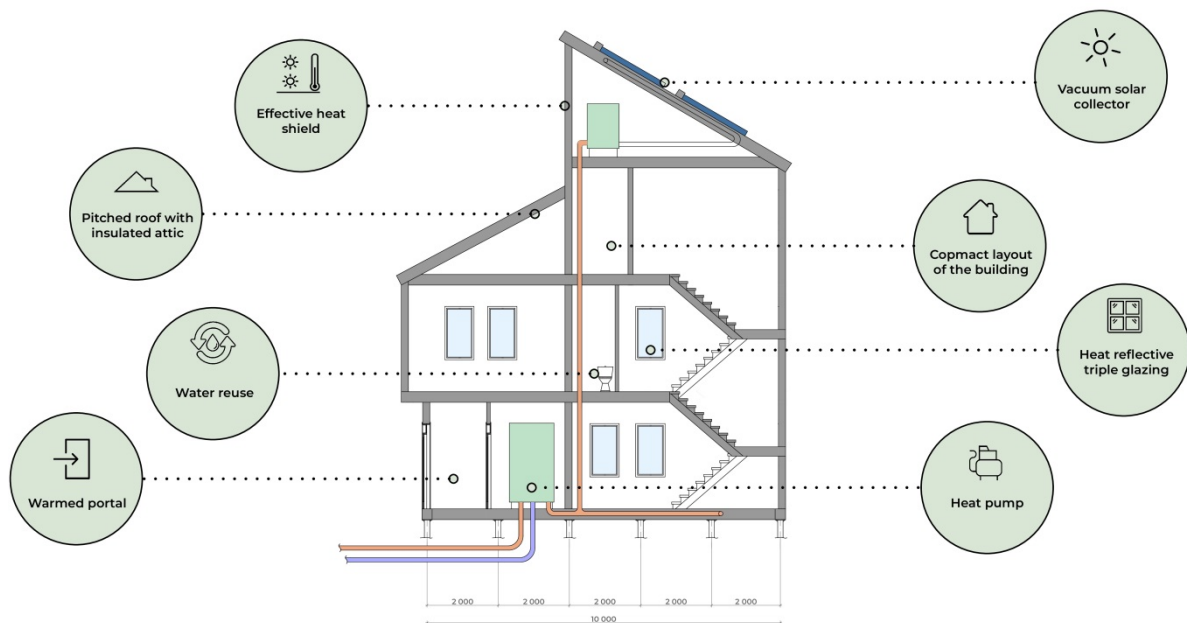


Figure 5. The scheme of energy-efficient low-rise houses for the Ural region.



Figure 6. Facade solutions for an energy-efficient low-rise house for the Ural region.

Energy-efficient technologies and renewable energy sources acceptable to the Urals was analyzed. The presented concept of an energy efficient house corresponds to the energy saving and energy efficiency strategy for low-rise construction in the Ural region, based on its climatic features. That, in turn, is a definite impetus to the development of energy-efficient construction in Russia as a whole.

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